NATIONAL TRANSPOPRTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C.

May 11, 2000

Group Chairman's Factual Report - Flight Data Recorder

A. ACCIDENT

DCA00MA006

Location	:	About 60 miles south of Nantucket, Massachusetts
Date	:	October 31, 1999
Time	:	About 150 EST
Aircraft	:	EgyptAir Flight 990, a Boeing B-767-300ER, SU-GAP

B. GROUP IDENTIFICATION

Chairman	:	Thomas R. Jacky, NTSB
Member	:	Tim Mazzitelli, The Boeing Company
Member	:	Bob Henley, Federal Aviation Administration
Member	:	Dennis Chandler, Pratt & Whitney
Member	:	Brad Morrison, Federal Bureau of Investigation
Member	:	Captain Mohsen El-Missiry, Ministry of Civil Aviation, Egypt
Member	:	Elsayed Elbadawi, EgyptAir
Member	:	Mourad Shawky Fadallah, Egyptian Civil Aviation Authority
Member	:	Mostafa El Gammal, EgyptAir

The group convened at NTSB headquarters in Washington, D.C. from November 9 to 15, 1999 for readout of the FDR. Group activities included transcription and waveform recovery and reconstruction of the accident flight data. In addition, a transcription of the entire 25-hour contents of the FDR was accomplished.

C. SUMMARY

About 0150 eastern standard time (EST), on October 31, 1999, a Boeing 767-366ER, SU-GAP, operated by EgyptAir, as flight 990, crashed into the Atlantic Ocean about 60 miles south of Nantucket, MA. EgyptAir flight 990 was being operated under the provisions of Egyptian Civil Aviation Regulations Part 121 and United States Title 14 Code of Federal Regulations Part 129 as a scheduled, international flight from John F. Kennedy Airport (JFK), New York, New York to Cairo International Airport in Cairo, Egypt. The flight departed JFK about 0122 EST, with 4 flightcrew members, 10 flight

attendants, and 203 passengers on board. There were no survivors. The airplane was destroyed by impact forces. Floating debris from the aircraft was recovered on the morning of October 31, 1999.

The accident airplane's flight data recorder (FDR), a Sundstrand Data Corporation (SDC - now named Honeywell Aerospace Electronic Systems) Universal Flight Data Recorder (UFDR) part number 980-4100-DXUS, serial number unknown, was retrieved from the Atlantic Ocean on November 9, 1999 by the United States Navy. The FDR was immersed and sealed in an ice chest containing water and transported to Andrews Air Force Base, Maryland the same day. NTSB personnel took custody of the FDR at Andrews Air Force Base and moved the FDR to the Safety Board laboratory in Washington, D.C.

Readout of the FDR was accomplished using the laboratory's playback hardware, NAGRA tape recorder and interface connected to a Hewlett-Packard HP9000 minicomputer running TSB Canada-developed Replay And Presentation System (RAPS) software.

The group transcribed the entire accident flight. The waveform recovery utility included in the RAPS software was used to correct areas of weak FDR signals, especially at the end of the accident flight data. However, after completion of the waveform recovery techniques, the final composite file of the accident flight data did not contain synchronization loss, and a complete, anomaly-free recording of the flight, from takeoff through end of data, resulted.

Data plots and tabular listings of each data parameter for the entire accident flight are included in this report. The entire 25-hour contents of the FDR were also transcribed, and the data provided to the parties to the investigation.

The elapsed time of the accident flight transcription was converted to local time by correlation of the recorded pressure altitude data to recorded radar altitude data. A time correlation between the cockpit voice recorder (CVR) timing was compared to the FDR Very High Frequency (vhf) microphone keying and a time correlation developed.

Transcription of the accident flight and observation of the resultant data determined in the following points:

1) The accident flight, as transcribed, was 29 minutes, 50 seconds in duration. The transition of the Air/Ground discrete parameter from "Ground" to "Air", occurred at 1:20:45.98 EST, and the final subframe of data was recorded at 1:50:35.98 EST.

   The transcription file used for this report contained approximately 44 minutes of aircraft operation regarding the accident flight. The transcription file also included the landing of the leg immediately prior to the accident flight (i.e., SU-GAP's JFK landing), as well as data following the FDR's transition to 25-hour-old data.

The end of data from the previous flight was at 23:48:31 EST, October 30, 1999. The first subframe of accident flight data occurred at 1:06:22.98 EST.

2) The FDR data indicates that, after takeoff and climb, the airplane was level at a pressure altitude of 33,000 Feet (recorded as 32,992 ft) and an easterly magnetic heading of 80.51º, when the Auto-Pilot Command Center discrete changed state, from "engaged" to "not engaged", at 1:49:44.98 EST.

3) About 7 seconds later, at 1:49:51.98 EST, the Throttle Resolver Angle Engine 1 and 2 parameter values reduced from 59º to values of 36.69º and 35.95º, for the left and right throttle, respectively, at 1:49:52.98 EST.

   Thrust Resolver Angle for both engines were recorded at approximately 34º from 1:49:52.98 EST until 1:50:23.98 EST, when Thrust Resolver Angle was recorded as 84.11º and 84.99º, engine 1 and 2, respectively. Both Thrust Resolver Angle values were recorded at approximately 85º for the remainder of the accident flight data.

4) Two seconds later, at 1:49:52.98 EST, the Left and Right Elevator Position data, previously recorded at approximately neutral values, indicated increasing trailing-edge down (TED) values. From 1:49:54.98 EST to 1:50:04.98 EST, the Elevator positions were recorded at about -3º TED. The elevator position data decreased further, so that from 1:50:05.98 EST to 1:50:15.98 EST, the values were between -4º and -5º TED.

5) Prior to the change of the Auto-Pilot Command Center discrete from "Engaged" to "Not Engaged", Vertical Acceleration values were recorded at about 0.98 G's. At 1:49:44.98 EST, after the Auto-Pilot Command Center discrete changed to "Not Engaged" and elevator position data decreased to trailing edge down values, vertical acceleration values decreased from values about 0.98 G's to about 0.91 G's at 1:49:51.98 EST. The values then began decreasing to a local minimum, at 1:49:54.98 EST, of 0.066 G's. The values then increased to a local maximum, at 1:50:03.98 EST, of 0.190 G's. The values then decreased and remained below zero G's from 1:50:05.98 EST to 1:50:13.98 EST, including a minimum value of –0.227 G's, at 1:50:08.98 EST. The vertical acceleration values then increased so that, by 1:50:18.98 EST, the values were greater than 0.98 G's.

6) Pitch Attitude values decreased from approximately 3º aircraft nose up (ANU) at 1:49:45.98 EST to a minimum value of –40.25º aircraft nose down (AND) at 1:50:14.98 EST.

7) The Engine Low Oil Pressure Left and Right discretes changed state from "Normal", last recorded at 1:50:04.98 EST and 1:50:06.98 EST, left and right, respectively, to "Low" at 1:50:08.98 EST and 1:50:10.98, left and right, respectively. The "Normal"states were

again recorded at 1:50:20.98 EST and 1:50:22.98 EST, left and right, respectively. The parameters were recorded as "Normal" for the remainder of the recorded data.

8) Throughout the accident flight, the Master Warning Captain and First Officer (F/O) discretes were recorded as "No Warning" until 1:50:07.98 EST. The Captain and F/O discretes were then recorded in the "Warning" state for the remainder of the recorded data.

9) The Thrust Management Computer (TMC) Auto-Throttle Engage discrete changed state, from "Operational" to "Inop", at 1:50:16.98 EST, and remained as "Inop" for the remainder of the recorded data.

10) At 1:50:20.98 EST, the Engine Start Lever Right discrete changed state from "Engine Run" to "Cutoff". The Engine Start Lever Left discrete changed state, from "Engine Run" to "Cutoff", at 1:50:21.98 EST. The Engine Start Lever Left and Right discretes were both recorded as "Cutoff" for the remainder of the recorded data.

    Within 3 seconds following the cutoff of the engines, several engine parameters exhibited 1-second spikes in the recorded data. At 1:50:21.98 EST, the Throttle Resolver Angle 2, N2 Engine 2, Exhaust Gas Temperature (EGT) Engine 2, and EPR Engine 2 values all recorded data spikes. At 1:50:22.98 EST, the N1 Engine 1 parameter recorded a data spike. Although the values, as recorded by the FDR, were valid, the aircraft engine and airplane manufacturers indicated that the values were actually erroneous, and a characteristic of the engine shutdown sending erroneous data to the airplane's data buss and flight recorder system.

    Despite the engine parameter spikes, after the Engine Start Lever discretes recorded "Cutoff", the Left and Right Engine N2 values decreased from 74.62% and 74.94%, respectively, at 1:50:20.98 EST, to final recorded values, at 1:50:35.98 EST, of 52.12% and 53.06%, left and right engine, respectively.

11) Until 1:50:20.98 EST, the recorded elevator data (left and right position each sampled at 1 hertz) values were within ±1º for each second of data. However, beginning at 1:50:21.98 EST, elevator data diverted by differences greater than 1º. In addition, while the left elevator values for the remainder of the recorded data were trailing edge up (TEU), including a local maximum of 3.87º TEU at 1:50:29.98 EST, the right elevator values for the remainder of the recorded data were trailing edge down (TED), including a local minimum of –3.16º TED at 1:50:28.98 EST. However, the relative trend of the elevator data, as indicated by the remainder of the accident flight data, was towards neutral position.

12) During cruise flight at 33,000 feet, the outboard aileron position data indicated values of about 2º and 3º TEU, left and right outboard aileron, respectively, until 1:50:12.98 EST. Both outboard ailerons then indicated movement towards neutral until 1:50:17.98 EST, when both outboard ailerons indicated increasing TEU values. From 1:50:17.98 to

1:50:26.98 EST the difference between the outboard aileron data values was less than approximately ±1.5º for each subframe. From 1:50:27.98 to 1:50:30.98 EST the difference between the aileron values increased and reached a maximum difference of 4.57º at 1:50:30.98 EST, with 9.67º TEU and 5.10º TEU left and right outboard ailerons, respectively. From 1:50:31.98 EST until the end of recorded data, the difference between outboard aileron positions was less than ±1.5°.

In addition, both inboard aileron values indicate TEU values from 1:50:20.98 EST through the end of the accident data.

13) Speed Brake Handle Position was recorded at about 4.0% until 1:50:24.98 EST, when the recorded value was 7.8%. One second later, at 1:50:25.98 EST, the recorded value was 99.2%. Speed Brake Handle Position was recorded at approximately 99% position for the remainder of the accident flight data.

14) During the last subframe of recorded data, at 1:50:35.98 EST, pressure altitude was recorded as 16,416 feet, while the computed airspeed was recorded at 458 knots. Pitch attitude values increased to a final value of –7.91º AND, and the final vertical acceleration value was 2.421 G's. The final engine N2 values were 52.12% and 53.06% for the left and right engine, respectively.

D. DETAILS OF INVESTIGATION

1. Description of Recorded Data

This model FDR records airplane flight information in a binary format, using analog signals, onto eight tracks of 1/4-inch Mylar tape using an analog signal. The FDR records 64 words of digital information every second, with each word 12 bits in length. Each grouping of 64 words (or 768 bits) is called a subframe. Each subframe has a unique 12-bit synchronization (sync) word identifying it as either subframe 1, 2, 3, or 4. The sync word is the first word in each subframe. Each grouping of consecutive 1, 2, 3 and 4 subframes comprise a frame (i.e., four seconds of data). The data stream is "in sync" when successive sync words appear at the proper 64-word intervals. Each data parameter (e.g. altitude, heading, and airspeed) has a specifically assigned word number within the subframe.

If the data stream is interrupted, the sync words will not appear at the proper interval or sequence and sync will be lost along with the surrounding data. A loss of data synchronization can result from either a mechanical or electrical interruption of the data. Foreign matter between the tape recording medium and the heads during the record or playback process can cause a mechanical interruption. Mechanical interruptions can also be caused by airframe vibration, which can introduce wow and flutter to the tape transport and distort the recorded signal. An interruption of electrical power to the recorder will also

interrupt the serial data stream and cause a loss of sync. Finally, an interruption of the serial data stream to the FDR will also cause a loss of synchronization.

FDRs are required to retain the airplane's most recent 25 hours of operation. This is accomplished by erasing the oldest data and replacing it with the newest. The UFDR records onto the Mylar tape 8 distinct, individual tracks. The tracks are written bi-directionally. The UFDR records approximately 3 hours of data on each track until reaching end-of-tape sensors, then reverses tape direction, increments the recording track, and writes data in the reverse direction on the tape. Using this method, the FDR records even-numbered tracks in one direction, odd-numbered tracks in the opposite direction.

The UFDR utilizes a data-checking process known as "check-stroke". The data are written onto the FDR tape in "bursts" of 1 subframe of data (768 bits). The UFDR adds a series of preamble and postamble bits to the beginning and end of each seconds-worth of information. After writing the seconds-worth of data, the tape is stopped, reversed and read for accuracy. The tape is then advanced, past the most recent written second of data and stopped. The next second of data is then written. By writing the data onto the tape in this manner, a segment of unused or blank tape is created. The unused segment is known as an inter-record gap (IRG). The result of the check-stroke recording method is an alternating pattern of consecutive second's-worth of data, separated by IRGs. The pattern can be viewed optically with the use of a magnetically sensitive fluid. The inter-record gap and each second of data measure about 0.48 inches along the FDR tape.

However, the UFDR's method of operation does not guarantee that the first word written within each second's-worth of data is the synch word; rather than appear at the beginning of each second's-worth of data, the inter-record gap can appear at any point within the 64-word subframe. Each second's-worth of data may contain data that span 2 consecutive subframes. Therefore, a specific subframe of data can bridge an inter-record gap.

Also, because of the check-stroke operation, flight data is multiplexed and stored within a buffer, such that while one second's-worth of data are being written to tape, the next second's-worth of data is being collected and stored in memory. It follows then, when power is removed from a UFDR, depending on where in the checkstroke process the UFDR is at, up to one second's-worth of data may not be written to tape, and therefore lost.

The transition from the most recently recorded data to the oldest data is normally detected by examining the recovered data for a discontinuity; for example, a significant change in heading, airspeed, altitude, etc. Another method of determining the data transition is to apply a magnetically sensitive fluid to the tape and examine the tape for a section of tape without data. This should correspond to the physical distance between the erase and record heads, approximately 3 inches of tape.

For this airplane's FDR system, the FDR receives a serial binary data stream from the Digital Flight Data Acquisition Unit (DFDAU). The DFDAU retrieves data sent from various sources (e.g. data buses, analog sensors, etc.) throughout the airplane. The DFDAU collects, conditions, and converts these analog and digital signals into the serial data stream. The data stream is then sent to the FDR, which converts the digital data stream into analog, Harvard Bi-Phase waveforms. The waveforms are then recorded on the FDR tape.

The airplane and DFDAU manufacturer (Teledyne Controls of Los Angeles, California) provided document number SCD 2227000-62, Digital Expandable Data Acquisition and Recording System (DEFDARS). A listing of the parameters recorded by the FDR is included in Attachment 1.

In addition, the Teledyne documentation indicated that the DFDAU identifies Non-Computed Data (NCD) when the DFDAU reads bits 30 and 31 of the appropriate ARINC 429 Data Bus word as "01". The DFDAU indicates NCD to the FDR by setting bits 9-12 of the subsequent output FDR word to first "0110" and then "0000" at 4-second intervals. The pattern is repeated as long as the DFDAU identifies the data as NCD.

2. Examination and Readout

a. Examination

The U.S. Navy recovered the FDR from the floor of the Atlantic Ocean on November 9, 1999. The same day, the enclosure was transported to the Vehicle Recorder Division's laboratory in Washington, D.C. Since the FDR was not waterproof, the tape media was exposed to water. To protect the tape from corrosion, the FDR enclosure was immersed in water and transported to the NTSB laboratory in a beverage cooler.

Upon receipt, the FDR was removed from the cooler and examined for damage. The FDR's outer sleeve and internal electronics were subjected to impact damage. The FDR's faceplate was partially removed from the casing; only the cable from the external equipment connector (i.e., data plug) held the faceplate to the FDR. The nameplate attached to the faceplate was missing; therefore, the unit's serial number could not be determined. Finally, the underwater locator beacon (ULB) and ULB mount were missing from the faceplate. Photographs of the FDR documenting the damage were included in Attachment 2.

After cutting the wires from the external equipment connector, the faceplate was detached from the FDR. The FDR's armored enclosure was removed from the FDR. Each of the four shock mounts holding the armored enclosure in the FDR was broken. However, the armored enclosure exhibited only minor damage, and the four bolts holding the armored enclosure together were intact.

The four bolts from the armored enclosure were removed. The coverplate to the tape platform was removed, exposing the tape reels. The FDR tape did not exhibit any physical damage. The position of the tape and reels were noted for future reference. The entire tape was wound onto one of the platform's reel hubs, the hub and tape removed from the transport, and the tape transferred to an empty 5½-inch tape reel. The FDR tape was then cleaned and dried.

b. Readout

The FDR tape was placed onto the NTSB's Nagra tape recorder for transcription using the Board's RAPS software. The tape was positioned to the reference position noted upon opening the tape protective enclosure. Each of the tape's eight recording tracks were then searched for data consistent with the accident flight, followed by a data transition (from newest to oldest data). Once the transition was discovered (on track 3 of tracks 0 through 7), the tape was repositioned to the area prior to the accident flight takeoff. The previous approach, landing, and entire accident flight through the data transition were then transcribed into a computer file for further processing. Several transcriptions were attempted to acquire a complete waveform through the accident sequence and transition from newest to oldest data.

The transcribed data were reduced from the recorded binary decimal values (0 to 4095) to engineering units (e.g., feet, knots, degrees, etc.) by the conversion formulas obtained from the airplane and FDAU manufacturer. An automated process that incorporates the laboratory's computer and associated software accomplishes the actual conversion.

Elapsed time, or FDR Subframe Reference Number, from the beginning of the data transcription was initially used as the time base for data output. In addition, The FDR recorded an independent time source derived from the Captain's clock (e.g., Coordinated Universal Time (UTC), or Greenwich Mean Time (GMT)) to provide corroborating timing information. Later, the data were correlated to the Nantucket Airport Surveillance Radar (ASR) Eastern Standard Time (EST), as described below in section 4.

Inspection of the transcribed data revealed the recorder operated normally, except for several minor losses of synchronization throughout the accident flight. Utilizing RAPS' bitwave analysis module (described below), the synchronization losses were corrected.

3. RAPS Bitwave Analysis of Data

Inspection of the final subframes of data prior to the transition to oldest data indicated that RAPS digitized the waveforms, but was unable to determine whether the waveforms were "1"s or "0"s. The transcription indicated the recorded signal was weak in this area of the tape. Further inspection revealed that several subframes of data were digitized but not fully decoded. Therefore, it was necessary to manually decode the data.

Readout of the FDR was accomplished using the laboratory's playback hardware, NAGRA tape recorder and interface connected to a Hewlett-Packard HP9000 minicomputer running TSB Canada-developed Replay And Presentation System (RAPS) software.

The waveform recovery utility included in the RAPS software was used to correct the areas of weak FDR signals, especially at the end of the accident flight data and into the area of 25-hour old data.

This data were recovered to a waveform file and then manually decoded using bitwave analysis.

In addition, each synchronization loss throughout the accident flight was inspected for erroneously transcribed data. Each of the errors was corrected. When completed, the corrected frame data were combined with the in-sync data to form a composite transcription file. The resultant composite data file was complete and error-free from the moment of FDR start through the end of the recorded accident flight data. Normal data reduction techniques were then used to convert the composite data to engineering units and discrete values.

4. Correlation of FDR data to Radar Local Time

Based on information supplied by the Aircraft Performance Group Chairman, the time of each subframe of accident flight FDR data were adjusted to local time (Eastern Standard Time). By correlation of Mode C radar data returns recorded by the Nantucket Airport Surveillance Radar (ASR-9), each second of FDR data were adjusted using the following equation:

Local Time = (FDR Elapsed Time) + 418.98 seconds

The adjusted Local Time was used for all the accident flight data and is indicated on all plots and tabular output. For more information regarding the computation of the correlation, see the Aircraft Performance Study.

5. Tabular Printouts and Data Plots

Tabular sets of selected FDR parameters for the approximate final 12 minutes of recorded accident flight data, from 1:38:00.98 EST to 1:50:35:98 EST, is included in Attachment 3. Due to a limited amount of parameter space per page, the data were included in multiple data sets. Data from different tabular sets can be aligned by the use of Local Time.

Plots of selected parameters of accident flight data are included in Attachment 4. Due to a limited amount of parameter space per plot, seven sets of plots are included. Each set of

plots covers the time period from 1:38:40 EST through the end of FDR, to 1:50:40 EST. Each plot denotes 3 minutes of data.

The final plot included in Attachment 4 is a "waterfall plot" which details selected, critical parameters and covers the time period from 1:49:40 to 1:50:40 EST

6. Transcription and Examination of Entire Contents of Accident FDR

The entire contents of the FDR were transcribed using the Safety Board's Sundstrand UFDR Interface Unit. The FDR was transcribed at high speed into a binary computer file on the Safety Board's VAX computer. Each of the FDR's eight tracks was recorded into separate computer files. These files were used for all further examination of the 25-hours of data.

Tabular data of selected parameters for the entire contents of the FDR were developed and provided to the Egyptian Delegation on compact disc (CD).

7. Re-Transcription of Accident Flight For Egyptian Delegation

At the request of the Egyptian Delegation, in January 2000 the group chairman hosted a FDR specialist from EgyptAir to review the accident flight data and the method used to develop the data. During the review, another transcription of the accident flight was conducted for the benefit of the EgyptAir specialist. The second transcription replicated the first transcription. Plots of the second transcription were provided to the EgyptAir specialist.

In addition, the NTSB provided the Egyptian Delegation a CD with data from the entire 25 hours of airplane operations, as recorded by the FDR.

Tom Jacky
Aerospace Engineer

Attachments

1. List of Recorded Parameters
2. Photographs of Damaged FDR
3. EgyptAir Flight 990 FDR Tabular Data Sets
4. Plots of EgyptAir Flight 990 FDR Data